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MARINER II

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MARINER II

MISSION PREPARATION

By the end of the summer of 1961, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology had proposed and had been authorized by the National Aeronautics and Space Administration (NASA) of the United States to proceed to design and conduct two launchings to Venus during the launch opportunity which would occur in the summer of 1962. Such a mission was consistent with the role assigned to JPL by NASA, namely, to execute projects for the unmanned exploration of the moon, the planets, and interplanetary space.

The decision to go to Venus was arrived at by first examining the major constraints on planetary missions: the general spacecraft configuration, the availability of the planets, and the capability of the launch vehicles of the United States.

Either of two general spacecraft design approaches could be followed. The attitude-stabilized spacecraft fixes itself in space on the planets on our sun and other stars. The spin-stabilized spacecraft is stabilized only along one axis by the gyroscopic action of spinning the total spacecraft. Although the former approach is more complicated, JPL considered it to be the logical choice for planetary missions due to its many advantages over the limitations of the spin-stabilized craft. The attitude-stabilized spacecraft could point solar cells towards the sun for power, point directional antennas toward the earth for greater ranges of communications, point directional instruments toward the target planets, and finally, be pointed for directional maneuvers.

The availability of the planets as targets is indicated in Figure 1 where distances to our nearest planets from earth are plotted as a function of time. Venus comes closer to earth than any other planet and this occurs every 19 months. Mars is the second closest and this occurs every 25 months.

These infrequent opportunities when planets are in range make planetary missions rather unique. Many of our space missions which miss a planned launch date by a month, merely do just that - slip a month. In a planetary mission, a one-month slip is more likely a 19 or 25 month slip in schedule.

Venus was the U.S. choice as its first planetary target simply because the other planets are even more difficult to reach. For example, flight times to Venus are typically 3 or 4 months, to Mars, 7 to 8 months, to Jupiter - 2 years. Communication ranges to a spacecraft flying by Venus are typically 36 million miles, while at Mars they would be 136 million miles.

To accomplish an identical mission at Mars as at Venus, would require considerably more weight for additional solar cells, transmitter power, attitude control gas, etc.

Two launchings were planned for increasing the probability of mission success because of the high-risk nature of the mission, due to the extreme technological challenges. Mariner, assuming it survived the accelerations, vibration, and changing atmospheric pressure of the ascent phase into space would then have to operate for 3 to 4 months unattended, except by a few remote commands, in regions of space never before travelled. The hostile environment of space was not completely understood, nor could it be fully simulated on earth. This environment included that of extreme vacuum, cold temperature,
direct solar and other forms of radiations.

The only launch vehicle available for such exploration was the two-stage Atlas-Agena.

The remaining questions were (1) how small a meaningful spacecraft could be designed. After all, there would be a considerable investment in launch vehicles alone, and too few scientific results would not make the mission worth the investment. (2) After determining (1), could the Atlas-Agena launch vehicle be modified in any way to raise its performance to place this spacecraft to Venus; and (3) could this effort be accomplished in 9 months, the time required to ship equipment to the Atlantic Missile Range (AMR) at Cape Canaveral to meet the summer launching opportunity in 1962.

In a three week period from 8 August 1961 to 1 September 1961, a conceptual design was completed. A Mariner spacecraft design which weighed 447 pounds appeared feasible and worthwhile, and furthermore it appeared within the realm of possibility over the next few months to improve the performance of the Atlas-Agena launch vehicle by 110 pounds, the amount required to place the 447 pound craft to Venus.

Figure 2 is a plot of C_3,the geocentric energy required to place a mass to the planet Venus in 1962,vs. possible launch days.

If the spacecraft weight could be held to 447 pounds and if the Atlas-Agena performance could be increased by 110 pounds there would be a 51 day period in which to conduct a launch. Such a launch period* was necessary since there was only one launch complex in the nation capable of launching a mission to Venus in 1962,and that was the launch complex called "Pad 12" at AMR. After the first launch, time to prepare for the second launch would be required on Pad 12. Although a schedule and plan was worked out, and crews were staffed to launch the second vehicle 24 days after the first, it was felt that the remaining 27 days would certainly be needed for technical or weather problems which might arise on both launchings. It is interesting to note the sensitivity of this curve of Figure 2. The Mariner space-vehicle, including the Atlas, Agena and spacecraft, fully fueled on the launch pad,stood as high as a building ten stories tall and weighed over a quarter of a million pounds. Yet by adding 3 pounds to either the spacecraft or the Agena, one would lose a day of the precious 51 days available to launch.

What then occurred from September 1961 until June 1962 is described in summary.

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*"Launch period" is the number of days of opportunity to launch to a planet. "Launch window" is the number of minutes during any particular day, that a launch to the planets may be conducted.

The various elements of the spacecraft had to be designed, fabricated and tested.

The spacecraft as a whole had to be made to operate properly as it was subjected to tests of the extremes of environment it would experience, such as the vibration of the launch vehicle ascent phase (see Figure 3), and the vacuum and thermal environment of the long cruise phase. Three Mariners were prepared for the two launchings (see Figure 4). There was no time for a prototype spacecraft which could be used to qualify the design. The prototype phase, so fundamental to development of this sort would have to be by-passed. The first planetary spacecraft the U. S. would ever assemble would have to be committed to flight.

The interface between the spacecraft and the Agena had to be designed and tested. Modifications to the Agena to lighten it by the 110 pounds had to be qualified and incorporated in the design. Two Atlas's and two Agena's had to be manufactured. The in-flight separation of the various components of the total Mariner space vehicle is shown in Figure 5.

The considerable amounts of ground support equipment for testing and operating the spacecraft had to be prepared and assembled. (See Figure 4)

Trajectories and firing tables had to be prepared. Instrumentation for tracking and telemetering had to be planned and provided by the Atlantic Missile Range. The Deep Space Instrumentation Facility (DSIF)* stations had to be modified to meet new demands of this new mission (See Figure 6). A space flight operations plan and facility for collecting and processing all data and acting on this data was prepared.

The Mission Preparation effort was accomplished with all equipment ready for shipment on schedule.

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*The DSIF consists of stations in Australia, Africa, and the United States, spaced around the Earth to allow continuous communication with the spacecraft as the Earth turns.

SPACECRAFT DESIGN

All three Mariners that were prepared weighed within 2 pounds of the target weight of 447 pounds. In the nested position under the launch vehicle nose fairing or shroud, they were 5 feet in diameter at the base and 9 feet 11 inches in height. In cruise position the solar panels spanned 16.5 feet. (See Figure 7 for spacecraft characteristics)

The spacecraft design employs a hexagonal ("hex") structure. Mounted about the structure are six case-like assemblies of electronic and electro-mechanical equipment. Above the "hex" is a superstructure for the mounting of scientific instruments and an omni-directional* communication antenna.

Hinged on the structure are two solar-panels, a four-foot diameter parabolic dish for long-range communications, and a radiometer scan system. These are actuator-driven devices and are latched into a fixed position for the ascent phase of flight. Once the spacecraft is free from the launch vehicle, explosive disconnecting devices are detonated which unlatch the hinged devices.

In flight the spacecraft is normally powered by 9800 solar cells mounted on 27 square feet of panel surface. These cells collect energy from the sun and convert it into electrical power. The raw power available from the cells increases as the spacecraft moves closer to the sun from the orbit of Earth to that of Venus, assuming no degradation due to radiation effects. In addition to the cells, a rechargeable battery is carried. This battery supplies power to the spacecraft during the ascent phase and during spacecraft maneuvers when the panels are not directed at the Sun. The battery, without the solar cells, could sustain the spacecraft power needs for approximately 9.5 hours.

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*The omni directional antenna is employed for radiation in all directions when the spacecraft is manuevering.

As mentioned earlier, the craft is attitude-stabilized in all axes - pitch, yaw, and roll. It uses the Sun and the Earth as its references. Stabilization is provided by ten cold gas jets fed by nitrogen from two titanium bottles. Prior to flight the bottles are pressurized to 3500 psi with 4.3 pounds of nitrogen - more than enough to stabilize the craft throughout its flight to Venus, perform the necessary midcourse maneuvers, and perform a minimum of four reacquisition maneuvers in case the craft is knocked out of Sun-Earth reference by foreign objects in space. The jets are linked by circuitry to three gyroscopes in a "hex" case, and to 6 Sun sensors mounted about the spacecraft structure. Additionally this circuitry is connected to another light sensitive device, the Earth sensor, mounted on the parabolic antenna.* In flight the Sun sensor system is first actuated and if the roll axis (See Figure 7) is not pointed towards the sun, the Sun sensors are so collimated as to provide error signals which are amplified and driven to zero as the spacecraft is turned by actuating the appropriate gas jets with the error signal. In a similar fashion the craft is fixed about the roll axis as the jets torque the craft until the error signal detected by the Earth sensor, a photomultiplier tube aligned with the beam of the parabolic antenna, is driven to zero. Since it is possible that the sensors could acquire some objects other than the Sun and Earth, such as the Moon, or the Agena carcass which also goes into orbit about the Sun, the capability is provided in the radio command system to unlock the spacecraft from its references and go through reacquisistion cycles.

The heart and brain of the spacecraft is contained in the Central Computer and Sequencer (CC&S) which occupies one of the "hex" cases. The CC&S provides basic timing for the spacecraft, particularly the a.c. power, the digital data system, and various stored or programmed flight events (such as the unlatching of the movable elements of the spacecraft mentioned earlier), Sun acquisition, Earth acquisition, the mid-course maneuver sequence, and the encounter sequence. Although weight limitations did not permit any redundancy in the equipment on board the spacecraft, virtually all programmed CC&S functions with the exception of the midcourse maneuver sequence were capable of being inserted into the spacecraft by radio-command from the Earth-based DSIF stations.

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*Parabolic antenna points a concentrated beam of radio energy to Earth when the spacecraft is fixed on the Sun and Earth, in order to extend communication ranges.

As it turned out in the flight of the Mariner II this capability was desperately required and indeed employed successfully for the initiation of the encounter sequence.near Venus.

After injection into space flight by the Atlas-Agena, and after determining by tracking from the DSIF stations where the spacecraft is going in relation to Venus, the Mariner design permits one more opportunity to correct its course into the target zone. This opportunity is known as the mid-course maneuver and employs the aforementioned attitude control system and a motor having a thrust of 50 pounds which is located in the center of the "hex." The thrust vector is aligned along the spacecraft roll axis. The liquid monopropellant motor uses storable hydrazine as a fuel, held in a rubber bladder inside the propellant tank. (See Figure 8) The motor is fueled to burn for 57 seconds but can burn as short as .2 seconds and can alter the spacecraft velocity from .7 foot per second to 200 feet per second. During the burning of the motor, the spacecraft is stabilized by an autopilot located in one of the cases which accepts stabilizing signals from the gyros and actuates movable jet vanes which extend into the exhaust of the motor.

The communication system linking the DSIF and the spacecraft has the capability of data transmission from the spacecraft, transmission of commands to the spacecraft, transmission of a very stable frequency to the spacecraft which is shifted in frequency and retransmitted back to earth for doppler velocity measurements. Additionally angle-tracking is performed on Earth of the received signal from the spacecraft. The data transmission to Earth includes not only the data from the six scientific experiments on board but also fifty-two separate engineering measurements of spacecraft temperatures, transmitter power, hinge angle positions, voltages, currents, tank pressures, etc.

These engineering measurements provide a means of continually evaluating the spacecraft for making operational command decisions and for the design of future spacecraft.

The doppler measurements are of such accuracy that in flight the radial velocity of the spacecraft was measured to accuracies of plus or minus one-tenth of an inch per second when the spacecraft was at 54 million miles and travelling away from the earth at 49,000 miles per hour.

One of the more challenging engineering problems, and one that proved near fatal to the mission was the problem of controlling the temperature of the craft. The spacecraft would look into black-space at the temperature of Absolute zero, at the same time being subjected to direct solar radiation as it travelled closer to the Sun. Meanwhile the various equipments operating would heat the spacecraft. Since a passive temperature control system (not one that had active refrigerant or heating equipment) was necessary due to weight limitations, extreme heating or cooling of elements of the craft beyond their design range could easily occur.

The passive temperature control is accomplished by heat shields, louvers, and a variety of surface finishes.

These surfaces control both the amount of internal heat dissipated into space and the amount of solar heat reflected away. All of these surfaces have to be handled with gloves since any foreign substance from the human body could upset the temperature balance of the craft.

The scientific instruments consist of experiments proposed by scientists as shown in Table 1.

As Mariner flies past the planet, the microwave radiometer scans the planet to detect radiation at two wavelengths: 13.5 and 19 millimeters.

Both wavelengths are detected by a parabolic antenna that measures 20 inches in diameter and is 3 inches deep. By flying into the target zone of the planet, this small dish can make measurements on the planet having resolutions which, if attempted from Earth, would require the construction of a parabolic antenna having a diameter of thousands of feet.

Before Venus encounter, the radiometer is turned on and starts a scanning motion at the rate of 1 degree per second. Lateral movement is provided by the motion of the spacecraft across the face of the planet.

The infrared radiometer is a companion experiment to the microwave radiometer and is rigidly attached to the microwave antenna. In this way, both scan the same areas of Venus.

The infrared radiometer experiment operates at wavelengths of 8.4 and 10.4 microns (a micron is one-thousandth of a millimeter).

The magnetometer is a cylinder located just below the Mariner's omni-directional antenna. In this way, the sensors are as far as possible from any spacecraft components that may have magnetic fields associated with them.

Inside the cylinder are three magnetic cores, each aligned along a different axis.

The three axes of the instrument are sensitive to 1/2 gamma, or a field strength roughly 100,000 times weaker than that of the Earth. The magnetometer can detect the presence of a small nail in one's shoe if he moved to within ten feet of the spacecraft.

The high-energy radiation experiment consists of an ionization chamber and a group of three Geiger-Mueller (G-M) tubes having different sensitivities. Together, they measure the number and intensity of ~~energy~~ energetic particles in interplanetary space and near Venus. These particles are primarily cosmic rays, which are made up of protons (the nuclei of hydrogen atoms), alpha particles (the nuclei of helium atoms), and the nuclei of heavier atoms, and electrons.

The measurement of these particles is intended to contribute significantly to the knowledge of hazards to manned space flight.

The purpose of the solar plasma detector is to determine the flow and density of solar plasma and the energy of its particles.

Solar plasma is frequently called "solar wind" and consists of charged particles that are continually streaming outward from the Sun.

The sensor for this experiment is mounted on the outside of one of the electronic cases in the "hex" of the spacecraft. The aperture of the analyzer is pointed along the roll axis of the spacecraft so that it will face the Sun.

As a charged particle enters the analyzer, it finds itself in a curving tunnel. The two sides of this tunnel are metal plates carrying static electric charges - one negative, the other positive. The charged particle is attracted by one plate and repelled by the other, and so follows a curved path down the curved tunnel. If it is moving too slowly or too rapidly, it runs into one wall or the other, but if it is moving at just the right speed, it passes to the end and is detected.

Periodically, the amount of voltage on the plates is changed and a different energy is required by the particles to get through to the collector cup. The voltage is automatically changed ten times. In this way, it is possible to measure a spectrum of particle energies.

The cosmic dust detector is designed to measure the flux and momentum of cosmic dust in interplanetary space and around Venus. It consists of a crystal microphone located in the center of a sounding plate.

OPERATIONS

Essentially all equipment was shipped to the Atlantic Missile Range (AMR) during the first week of June 1962. This equipment included three Mariner spacecraft, associated sets of ground support equipment, two Atlas stages, and two Agena stages. The Atlas was flown to AMR in a C-133 aircraft. (See Figure 9) The spacecraft were requalified after their shipment, calibrated, fueled, and armed for flight. The Atlas and Agena stages were also requalified at AMR and prepared for flight. One such preparation involves the installation of a Range Safety System.

The Range Safety System consists of an explosive charge which is carried on board the Agena and the Atlas. A command destruct receiver is carried on board the Atlas to receive a destruct signal should one need be sent. It is the function of the AMR Range Safety Officer, if the space vehicle is out of control, or is liable to impact on inhabited regions, to destroy the spacecraft vehicle.

The Mariner spacecraft was to be injected into space by using the parking orbit technique. The Agena and spacecraft would coast down to an optimum departure point in the South Atlantic where the Agena would then burn for a second time, injecting itself and the spacecraft into space. The earth rotates beneath this optimum point of departure, or injection point, (See Figure 10) and the time for launching to this point, the launch window, is limited.

The launch of Mariner I took place at 4:21 AM, AMR time, on 21 July 1962. Shortly after launch a fault in the guidance system of the Atlas resulted in an instability in flight which caused the Atlas to begin to yaw violently, at times to an angle of 50 deg. The Range Safety Officer on the basis of his plots knew the vehicle was out of control and sent the destruct command at 293 seconds after launch.

The Atlas and Agena were destroyed as the charges ignited. Mariner I operated till it impacted in the Atlantic Ocean.

Although Mariner II was scheduled for launch 24 days after 21 July, it was necessary to reschedule to permit the correction of the problems causing the failure of Mariner I. The launch of Mariner II occurred at 1:53 AM on 27 August on an azimuth of 106.8 deg. (See Figure 11)

The spacecraft vehicle rose vertically and rolled to the prescribed azimuth. The Atlas ground guidance system based at AMR then brought the space vehicle to its terminal point for Agena first ignition. The nose-fairing, or shroud, was jettisoned forward. The Agena-Spacecraft separated from the Atlas and pitched under the shroud to approximately the local horizontal. The Agena ignited the first time and completed its burn. The Agena-Spacecraft was now in an earth-orbit at an altitude of 115 miles, coasting down to a latitude of -14.8 deg. and a longitude of 357.9 deg., the optimum point for injection into space flight to Venus on this day, at this time. The Atlas, never reaching earth-orbital velocity, plunged back into the atmosphere.

Down the "injection corridor" from AMR, tracking and telemetry stations were operative at Grand Bahama Island, San Salvador, Puerto Rico, Antigua, Ascension Island, South Africa and on three instrumentation ships deployed in the South Atlantic.

Reports began to come up range from these stations that all expected events were occurring within fractions of a second of the predicted times, indicating that the first phases of the flight were going well.

- The Agena, through internal programming, ignited for the second time at approximately L + 24 min. At the end of this burning period the Agena-Mariner Spacecraft were injected into an orbit which would take them about the Sun. Two and one half minutes later the spacecraft separated from the Agena by explosive disconnecting devices. The Agena maneuvered 140 deg. in yaw and expelled unused propellants to retard its speed to insure its missing Venus. Mariner II was now free and slowly tumbling in space.

<u>Launch Plus 44 Minutes</u> - The CC&S ignited the explosive unlatching devices and telemetry signals verified the solar panels were extended.

Launch Plus 60 Minutes - The CC&S activated the Sun acquisition system and Mariner II oriented itself towards, and began to derive its power from, the Sun. It now was partially stabilized and rolled slowly about its roll-axis.

The spacecraft was increasing its distance from the earth in a radial direction, such that at about launch plus 1 1/2 hours, the rotational rate of the Earth exceeded that of the spacecraft, causing it to appear to reverse its direction as observed from Earth. (See Figure 11) The Mariner II had now come under the 24 hour/day surveillance of the Space Flight Operations Complex* and this surveillance would not cease until Mariner II ceased operating 129 days later.

Launch Plus 10 Hours - Continued tracking data indicated a miss distance at Venus of 233,000 miles, which was well within the correction capability of the spacecraft maneuver yet to be conducted.

Launch Plus 2 Days - Only engineering telemetry had been received from the spacecraft since launch and this would normally continue until the CC&S switched on the Magnetometer, Ion Chamber, G-M tubes, Cosmic Dust Detector, and Solar Plasma instruments on the 7th day. However all spacecraft equipment was in order, so while the spacecraft was at a range of 447,897 miles, the Johannesburg DSIF station transmitted the first radio command and the above instruments were successfully placed in operation.

Launch Plus 7 Days - At a range of 1.2 million miles a stored command in the CC&S activated the Earth acquisition system. Mariner II made one more complete roll and stopped rolling as the Earth sensor fixed on the Earth. The transponder was automatically switched from the omni-directional antenna to the parabolic antenna. The mid-course maneuver had been planned for the next day but there was some question as to whether the Earth sensor was fixed on the Moon rather than the Earth.

The maneuver could proceed in either case as long as one knew which reference to use.

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*This complex included the DSIF stations, computers at JPL, and the world-wide communication net interconnecting the Earth based equipment.

It was determined that if a day was allowed to go by a parabolic antenna hinge movement of 1.5 deg. would indicate the Earth sensor was locked on Earth. If the angle changed 7 deg., the sensor was locked on the Moon.

Launch Plus 8 Days - Telemetry measurements indicated a 1.5 deg. change in antenna hinge motion. Calculations were begun to direct the spacecraft from its miss-distance of 233,000 miles into a target zone as shown on Figure 12. The zone was on the sunlit side of Venus and the bounds were determined by the capture zone of Venus, scansector limits of the radiometers, and instrument sensitivity.

Launch Plus 9 Days - Midcourse Maneuver - On the 5th of September 1962 the prepared punched tapes containing the calculated commands were fed into the encoder at the Goldstone DSIF station. The first three commands which were transmitted were stored in a memory circuit in the CC&S, and they were a -9.33 deg. roll-turn, a -139.83 deg. pitch turn, and a 69 mile per hour incremental change in velocity from the motor while the spacecraft was travelling at a velocity of 60,000 miles per hour around the Sun. A fourth command to execute the sequence was sent at a range of 1,492,500 miles.

The spacecraft performed the sequence as portrayed in Figure 13. The maneuver was performed properly in all respects but with a slight inaccuracy. There was an effective 3 mph error in velocity in the system, resulting in not a 69 mile per hour, but a 72 mile per hour velocity change. which was determined by further tracking and orbit calculations. The effect of this inaccuracy is shown in Figure 12. Meanwhile Mariner II was to be well within the target zone. Upon completion of the maneuver the spacecraft automatically reacquired the Sun and the Earth. The complete operation required 4 hours 15 minutes and was much like conducting a missile launching by remote control at a range of 1.5 million miles.

Launch Plus 12 Days - The spacecraft lost Sun and Earth lock and reacquired in 3 minutes. All indications pointed to an impact of the spacecraft by a foreign object.

Launch Plus 33 Days - The spacecraft lost Earth lock and reacquired in 3 minutes. This was due, not to impact by a foreign object, but to a temporary fault in the Earth sensor. A fascinating record was obtained throughout the flight of Earth brightness from the sensor which showed a clear diurnal effect as the Earth alternately displayed land masses, clouds, and oceans to the spacecraft.

Launch Plus 65 Days - A short circuit occurred in one solar panel for an unknown reason. Analysis subsequent to the short circuit showed that the spacecraft, having moved closer to the Sun had more than enough power from the remaining unshorted solar cells to operate properly.

Launch Plus 91 Days - At 22.5 million miles the spacecraft passed the record range for communications.

Launch Plus 100 Days - It had been observed for some time that the temperatures throughout the spacecraft were about 40 deg. F hotter than planned for. This information projected to encounter with Venus indicated that some devices would be hotter than the limits at which they were tested on Earth, whereas others would be very near their limits. There was considerable anxiety as to whether all items on board would survive.

Launch Plus 104 Days - Four telemetry measurements, of the total of 52, failed. Undoubtedly one failed and blew the fuse which was common to the four. Telemetry measurements were expendable if necessary and had been fused to protect the spacecraft.

Launch Plus 107 Days - After operating to within two days of encounter without flaw, the CC&S failed to give a cyclic calibrate pulse which normally occurred every 16.6 hours. The lack of the pulse at this time in itself wasn't serious, but what it might portend was, namely, that the CC&S might not initiate the final encounter sequence.

Launch Plus 109 Days - Encounter - 14 December 1962 - As was suspected, the CC&S did not issue the signal to the spacecraft to switch to the encounter mode, so shortly after the spacecraft "rose" over the Goldstone horizon on the morning of 14 December, the backup command to switch to encounter mode was transmitted from Goldstone. At a range of 36 million miles it took 6 1/2 minutes for the command signal to travel to the spacecraft, the spacecraft to respond, and the telemetry signals to travel back to Earth. The telemetry signals identified the fact that the command was successful and that the radiometers were operating and scanning properly. Although the spacecraft was hot,

the spacecraft was indeed operating properly for the actual encounter with Venus which was to take place in six hours. Having verified the above, the space flight operation team members who took turns to eat a meal prior to encounter, were able to view Venus to the southeast as a bright single object in the early morning California sky. They realized that their spacecraft, which had just responded, was within that field of light, and closer to its target than moon is to Earth.

Mariner approached encounter with Venus at a speed of 86,000 miles per hour relative to the Sun and 39,000 miles per hour relative to Earth. (See Figure 14). At encounter it made three passes across the planet with its radiometers - the dark side of the planet, the terminator (the line separating the sunlit and dark side) and the sunlit side. (See Figure 15) The closest approach to Venus occurred at 11 hours, 59 minutes, 28 seconds, California time, at a distance of 21,648 miles off the surface of Venus. The gravitational effect of Venus was to deflect the spacecraft to a new direction from its approach direction and significantly change the velocity of the spacecraft. (See Figure 16) Mariner passed Venus sufficiently close that had one been riding on the spacecraft, Venus would have appeared 900 times greater than the full Moon appears on Earth. ?

An hour after scanning Venus, a command was transmitted successfully from Goldstone to the spacecraft to restore it to its cruise mode.

For the remainder of the flight the spacecraft continued to transmit science data and the spacecraft was employed to make communication threshold tests and generally evaluated to contribute to future designs.

Launch Plus 123 Days - 27 December - The spacecraft made its closest approach to the Sun, 65.5 million miles, at 9:10 PM, California time.

Launch Plus 129 Days - The last signal received from Mariner II was 11 PM, California time on the 2nd of January 1963. The last telemetry data received gave no clue as to why the spacecraft was no longer heard from on Earth. At that time it was 54 million miles from Earth and 5.7 million miles from Venus. It would now go into a 345.9 Earth-day orbit about the Sun. (See Figure 17)

Over its 129 day flight, it had sent back eleven million measurements as it travelled a course of 223.7 million miles through our solar system.

It will require years for scientists and engineers to evaluate all of the data which is duplicated on magnetic tapes and occupies considerable vault space. A summary of new information about Venus and interplanetary space determined from the flight of Mariner II follows:

SUMMARY OF RESULTS

Results of Tracking Mariner II

The accuracy of tracking and orbit determination is sufficiently accurate that it permits the spacecraft position with respect to Venus at encounter to be known to an accuracy of 10 miles.. The large number (22,000) of two-way doppler data points taken during the flight along with the oscillator stability contribute greatly to the accuracy.

As a result of decades of astronomical tracking the mass of Venus has been known to be 0.8148 times the mass of Earth to .05 percent accuracy.

Two weeks of tracking Mariner around encounter, measuring the effect on the spacecraft of Venus, provided a mass of 0.81485 to .015 percent with the ability to determine the mass to .005 percent accuracy.

Careful evaluation of Mariner tracking data has also permitted the determination of the mass of the moon to an accuracy ten times greater than it was known before.

The high accuracy tracking of the spacecraft has, and will through further evaluation, result in an improvement in knowledge of the mass of Venus, the precise location of tracking stations, the mass of the moon, and the astronomical unit (A.U. - the mean distance between the Sun and Earth).

Magnetic Fields - The magnetic fields measured perpendicular to the Sun-spacecraft line in interplanetary space were found to be typically 2 to 5 gamma at quiet times (The Earth has a magnetic field of about 30,000 gamma at the equator; 50,000 gamma at the poles) and was approximately parallel to the plane of the Earth's orbit. Some "Magnetic Storms" were observed, such as on 12 September 1962, causing the value to rise to 25. Fluctuation of 10 to 20 gamma occurred along the Sun-spacecraft line and correlated with changes in solar plasma flow.

As the spacecraft passed Venus, no rise in the average gamma value occurred above the interplanetary value. In fact there was a tendency for the small fluctuations to lessen in the vicinity of Venus. If Venus had a magnetic field similar to Earth, measurements of 100 to 200 gamma would have occurred. The radiation and solar plasma measurements mentioned later also confirmed this lack of magnetic field. The magnetosphere of the Earth traps radiation bands and repels solar plasma. Mariner II found that the radiation count rate did not increase, nor did the solar plasma velocity decline as it went by Venus. If Venus has any magnetic field, and it is structured as is Earths, it is less than 5 to 10 percent of Earth's.

This lack of a magnetic field, indicates that the planet Venus, completely hidden from visual observation by its cloud coverage, is either rotating very slowly, or not at all.

Solar Plasma - Forty thousand spectra were taken throughout the flight and solar plasma was detected in every spectrum. Not heretofore realized, plasma presumably is always present. The solar plasma is a flowing of charged particles from the Sun. The density of the particles were found to be 10 to 20 protons and electrons per cubic inch and their velocity varied from 720,000 to 1,800,000 mph. Twenty occasions were observed when the velocity increased by 20 to 100 percent as a result of disturbances on the Sun. It was observed that sharp increases in the density, velocity, and temperature of the plasma preceded the onset of sudden magnetic storms on earth. Since Mariner was inside Earth's orbit, it would first detect the plasma cloud and send the information to Earth at radio velocities. Later the cloud would arrive at Earth and affect the Earth's magnetic field. There was measured the effect of the solar plasma pushing about the interplanetary magnetic fields as it does the Earth's magnetic field.

Radiation Measurements - The ion chamber and two companion G-M tubes, which were omni-directional, found a constant flux throughout most of the flight even though the distance from the spacecraft to the Sun decreased by 30 percent. This indicates that these instruments were measuring steady galactic cosmic rays from outside our solar system. In fact there was only one occasion wherein a solar disturbance caused an effect on these instruments and that was 23-24 October 1962 when a stream of protons with energies near

25 MEV were detected. The total radiation exposure over the flight was only about 3 roentgens - the order of exposure one would experience in getting an X-ray. During the flare, some .25 roentgen was received. At least during the time of the Mariner cruise, there was no radiation hazard in space to man. Of course one must consider that the mission was conducted during a relatively quiet year of sun activity (See Figure 17)

The low-energy, directional, G-M tube detected 7 other smaller solar bursts of radiation during September and October and 2 in November and December.

Had Venus a Van Allen radiation belt like Earth, a 10,000 fold increase would have been observed by the low energy detector. Significantly, no change in radiation occurred during encounter in any of the detectors. Venus has no equivalent to our Van Allen belt.

Cosmic Dust - Only two particle hits were detected throughout the flight. No impacts were recorded in the vicinity of Venus.

Near earth satellite recordings have indicated a dust particle flux which is 10,000 times greater than the flux measured over the 223 million miles path of Mariner. Venus has no dust belt like Earth's.

Radiometers - There have been a number of models of the Venus atmosphere proposed to explain the puzzling high brightness temperatures* resulting from various ground-based microwave radiometric observations, among which there has been some lack of agreement. (See Figure 18) Furthermore most of these observations have been made at inferior conjunction. Due to the range, atmospheric, and phase effects there has been considerable uncertainty in the measurements. And of course, measurements from Earth, where the receiving antenna beamwidths subtend angles greater than that which the planet subtends, give an integrated temperature measurement. Mariner was able to make local measurements on Venus with good resolution.

The two most likely models were the Greenhouse, and Ionosphere models. In the Greenhouse model the solar radiation is trapped under the clouds to heat the surface to a high temperature. In the Ionosphere model the surface is cooler and the temperature appears hot. Due to a high density of electrons

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*The radiation that would come from a perfect radiator. Brightness temperature is lower than true temperature.

in the ionosphere, a density thousands of times that of Earth, causing electric activity would give false indications at high temperatures.

If the Greenhouse model were the true model, Mariner would see "limb darkening", or a higher brightness temperature when looking into the middle of the planet, and a lower temperature at the limb of the planet. If the Ionosphere model were the true model, "limb brightening" would occur, since looking along the edge of the planet, a greater path of high density electrons would be observed. (See Figure 19)

A clear, unquestionable, limb darkening was discovered by Mariner. Furthermore it was found that there was little difference in temperatures measured on the dark side versus those on the light side. All results confirm the Greenhouse model as being the true model.

Correcting the brightness temperatures, measured during the scan, for absorption characteristics of the atmosphere and other effects, it was found that Venus has a fairly uniform surface temperature of 800 deg. F, too hot to support any conceivable life form.

The infrared radiometer frequency of 10.4 microns was intentionally selected to be in the carbon dioxide absorption band. Since neither of the IR frequencies, being so high, would penetrate through the cloud layer, one would be able to detect breaks in the clouds and something about the CO_2 content, by observing differences in the results from the two frequencies. There had been controversy as to whether or not breaks in the clouds had been observed from Earth.

It is significant that both frequencies gave essentially the same results, indicating equivalent penetration of the clouds. Over the region scanned, there were no measurable cloud breaks. Furthermore the results imply that the clouds are quite thick with no appreciable radiation coming up to the upper layers of the clouds from the planet surface. The temperature in the clouds was found to be -30 deg. F and was the same for dark and light sides of the planet. Limb darkening was observed with the IR as in the case of the midrowave radiometer. The CO_2 (considered to be a major constituent of the Venus atmosphere) was so small its presence wasn't measurable in the upper clouds.

A fascinating cold spot which was about 20 deg. F cooler than any other direction observed, was clearly detected during the latter half of the terminator pass (Figure 15). Such a cold spot could be caused by a surface feature such as a very high mountain penetrating up into the clouds.

Although the hot surface would not support life, nothing Mariner observed rules out the existence of lower order life forms in the cooler upper atmosphere.

The Mariner mission has been mankind's first step to other planets in our solar system.